EDICON 2019

FOCUS MICROWAVES GROUP

AURIGA PULSED IV

mesuro

Effects of Harmonic and Base-Band Tuning on Linearity

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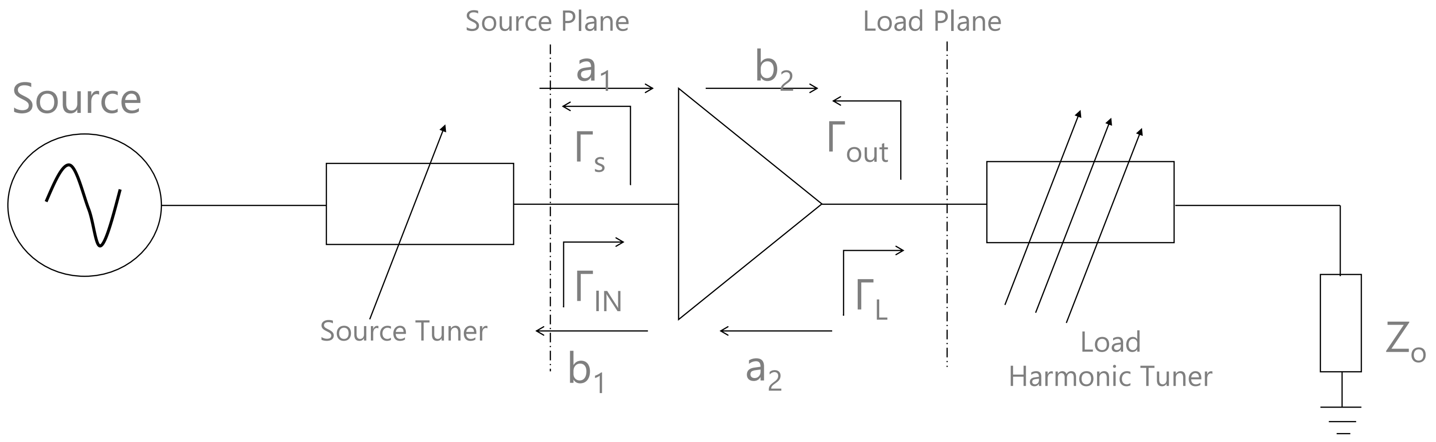
What is Load-Pull



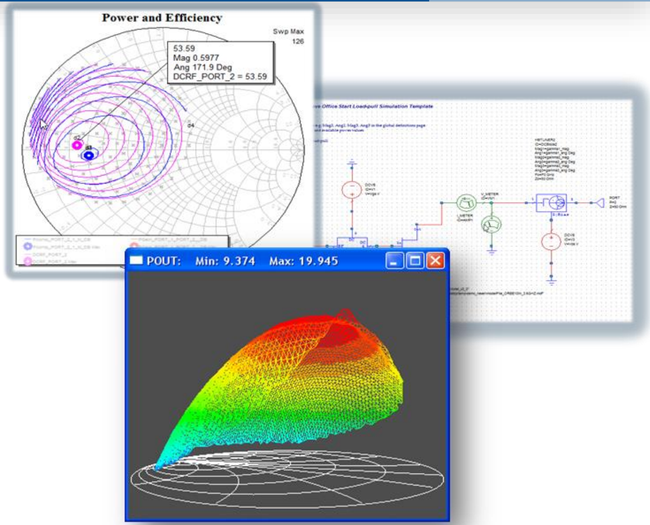
Load Pull

- An accurate measurement of key nonlinear performance parameters, including output power, gain, efficiency, linearity, etc. as a function of the fundamental load impedance, which is the key design parameter is typically referred to as *load-pull*.

Load Pull procedure consists of:

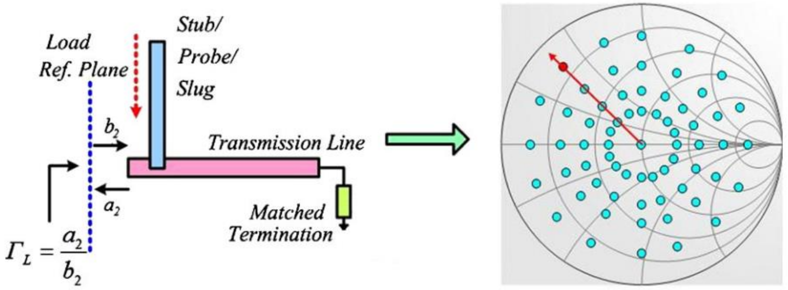
- Assessing the performance of the DUT qualitatively under different impendences
- Establishing a condition under which optimal performance can be obtained

Load Pull Measurements

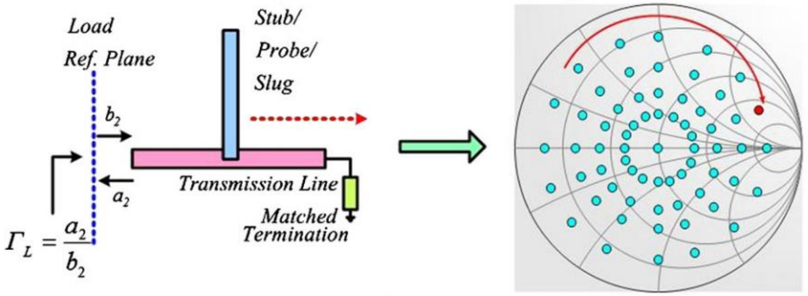


- Impedance control is provided by a passive tuner or an active tuner.

- An impedance tuner generates controllable reflection factor (Impedance) over a certain frequency range.



The movement of a stub/probe/slug in the vertical direction changes the magnitude of the reflection factor



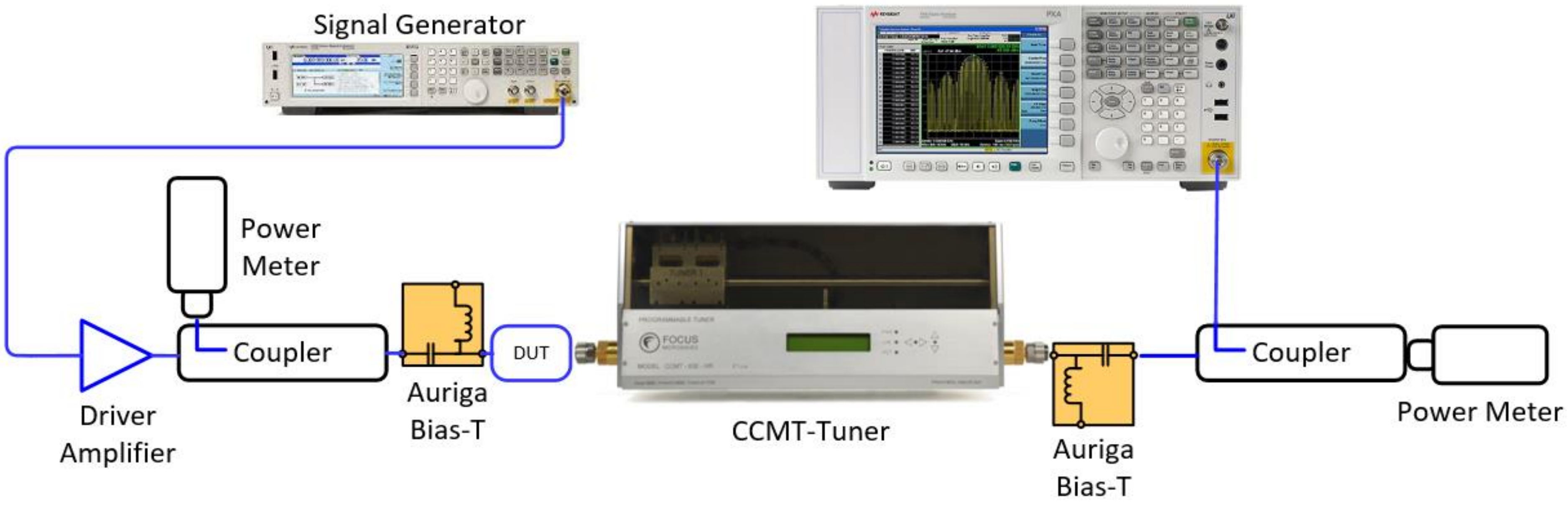
The movement of a stub/probe/slug in the horizontal direction alters the phase of the reflection factor

Load Pull setups -Scalar Load Pull

The typical scalar load pull setup comprises a signal generator, a power divider, two RF power sensors, a power meter, some DC bias networks and two fundamental tuners.

Measurements include:

- **Pin, Pout, Gain_{trd}, ACPR,**
- **Γ_{Load}, Γ_{source}**

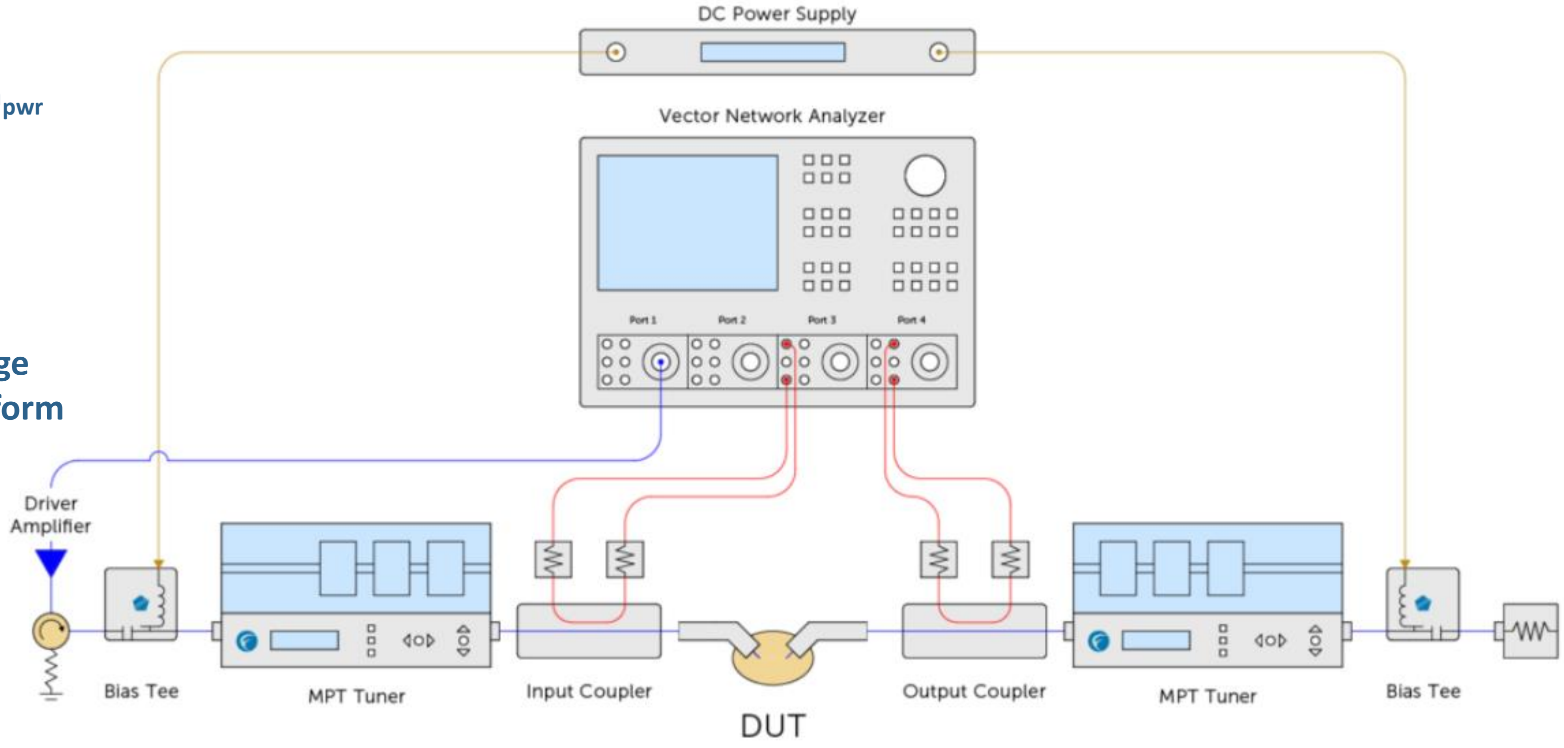


Load Pull setups – Vector Load Pull

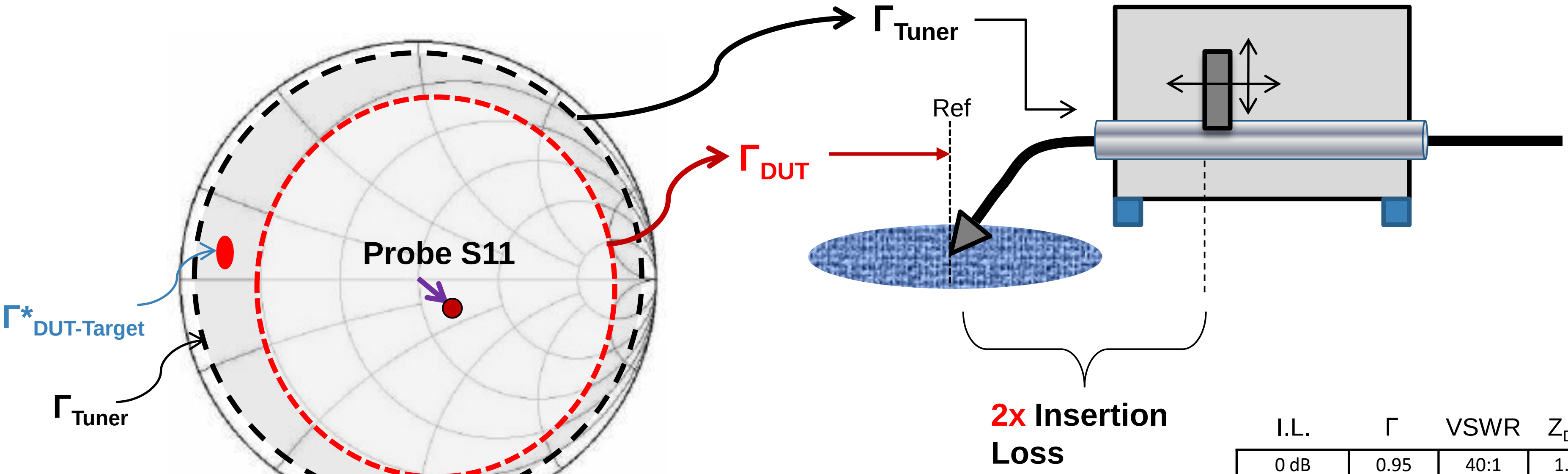
Vector Load Pull allows measuring the input and output large signal impedances of the DUT, the input delivered power, the Power added efficiency, and the real time incident and reflected waves thus not relying on mechanical tuner repeatability

Measurements include:
- **Pin, Pout, $Gain_{trd}$,$Gain_{pwr}$**
- **PAE, ACPR**
- **Γ_{Load}, Γ_{IN}**

Major advantage:
- **Speed**
- **Higher dynamic range**
- **Time domain Waveform**



Effects of Loss in Tuning Range



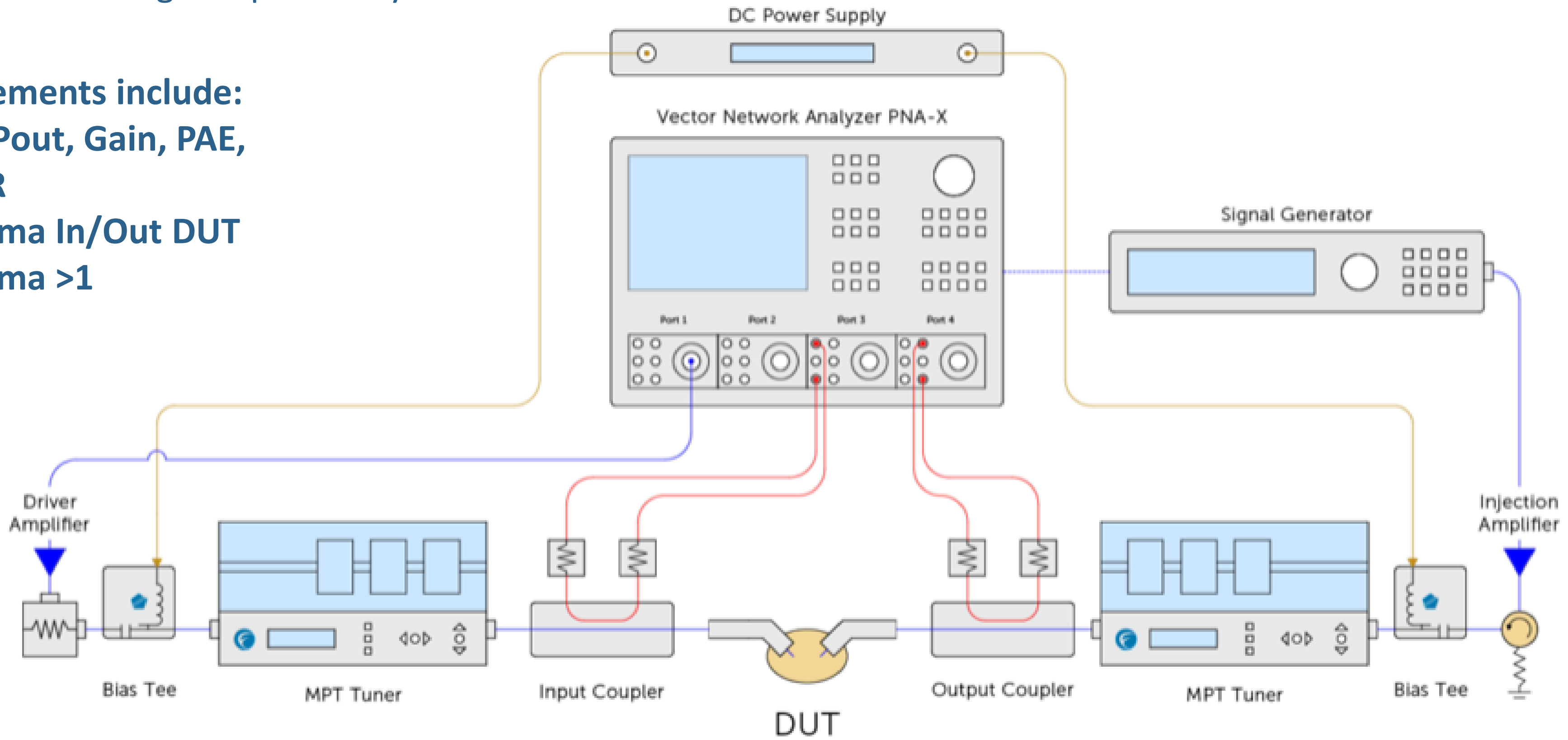
I.L.	Γ	VSWR	Z_{DUT}
0 dB	0.95	40:1	1.3Ω
0.1dB	0.93	27:1	1.9Ω
0.5dB	0.85	12:1	4.2Ω
1.0dB	0.76	7:1	7Ω

Load Pull setups – Hybrid Load Pull

As per its name a hybrid load pull system includes both an active loop as well as the passive tuners. The hybrid system has all the advantages of speed and tuning range of an active system as well as the power handling of a passive system.

Measurements include:

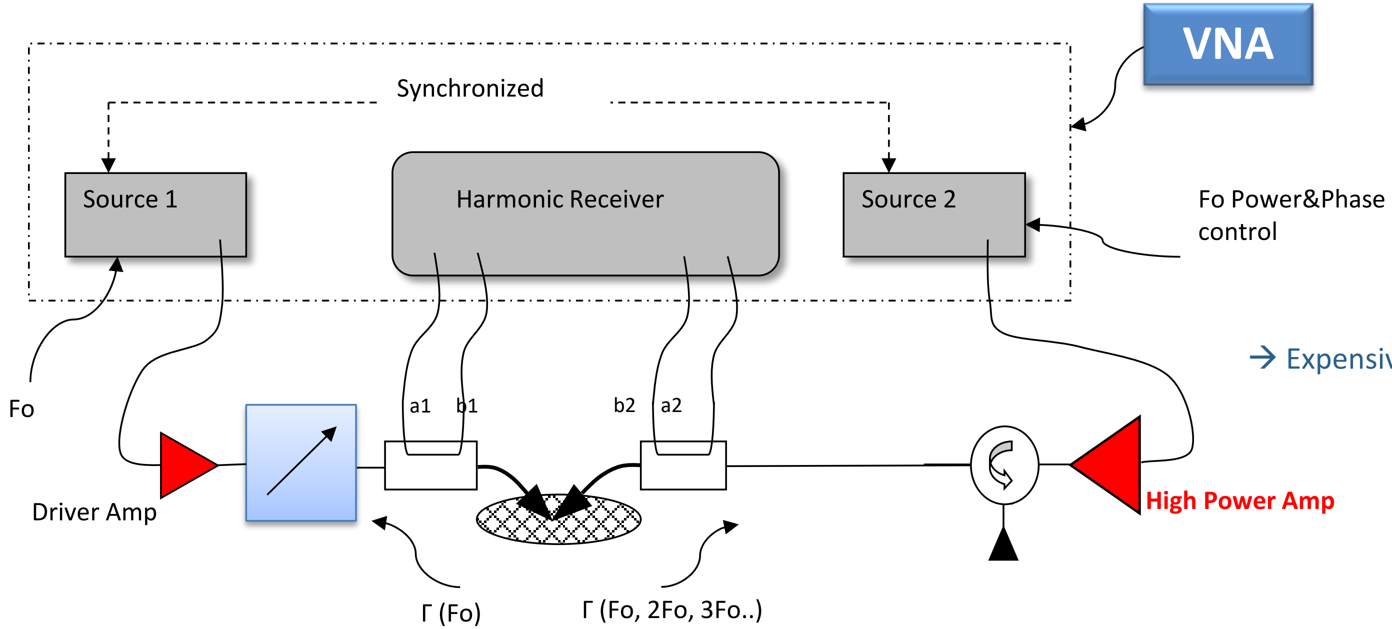
- **Pin, Pout, Gain, PAE, ACPR**
- **Gamma In/Out DUT**
- **Gamma >1**



The tuning algorithm finds the optimum compromise for tuner loss and P_{inj} for reaching Γload.

Active Load Pull – Basic Principal

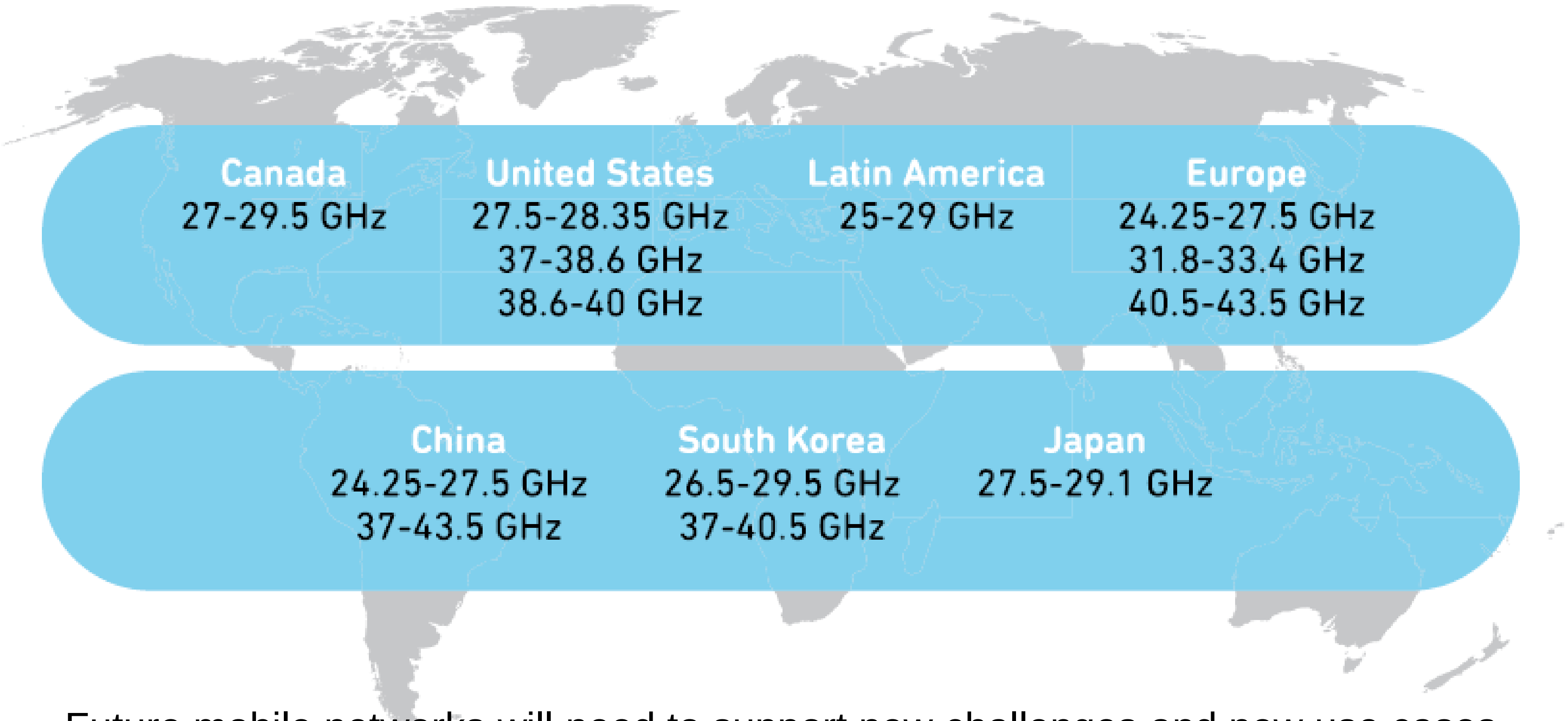
To achieve maximum reflection including the ability to control impedance anywhere, inside and outside of the Smith chart; reduced system footprint and perhaps most importantly speed, a full active LP system is used. Using the vector receiver architecture, Fundamental and/or harmonic load pull can be undertaken using a variety of configurations, either employing internal VNA sources or external RF sources and a PLL interface. By employing a broadband coupler network and in the case of harmonic measurements a reconfigurable multiplexer harmonic data can also be captured for use by designers.



Typically: $P_{inj} >> P_{dut}$
→ Expensive and frequency limited driving amplifier

The disadvantages of this setup is that a very high power active loop amplifier is required to synthesize low impedance points.

mmWave Applications
mmWave Worldwide bands

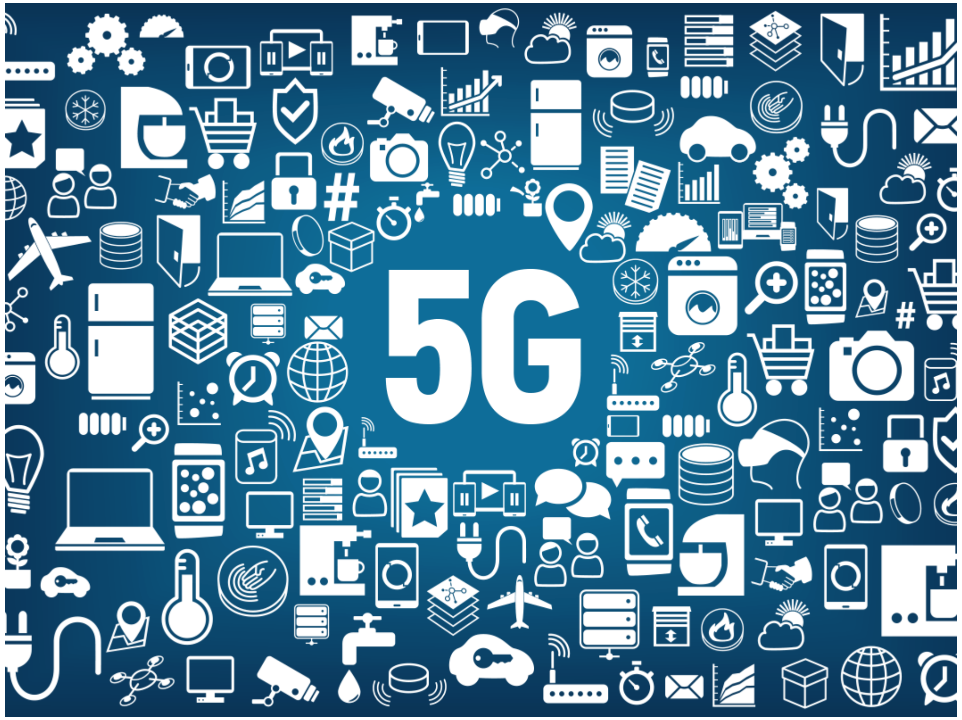


Future mobile networks will need to support new challenges and new use cases, which will demand more spectrum in ever higher frequency ranges.

Focus Solution for 5G Applications

Focus solutions for 5G Load Pull

Passive source/load pull Hybrid source/load pull	Delta tuners
Active modulated load pull	RAPID
Wideband Noise	Wide band Noise Parameter extraction



Tuner – DELTA
Tuners Designed for On-Wafer Applications

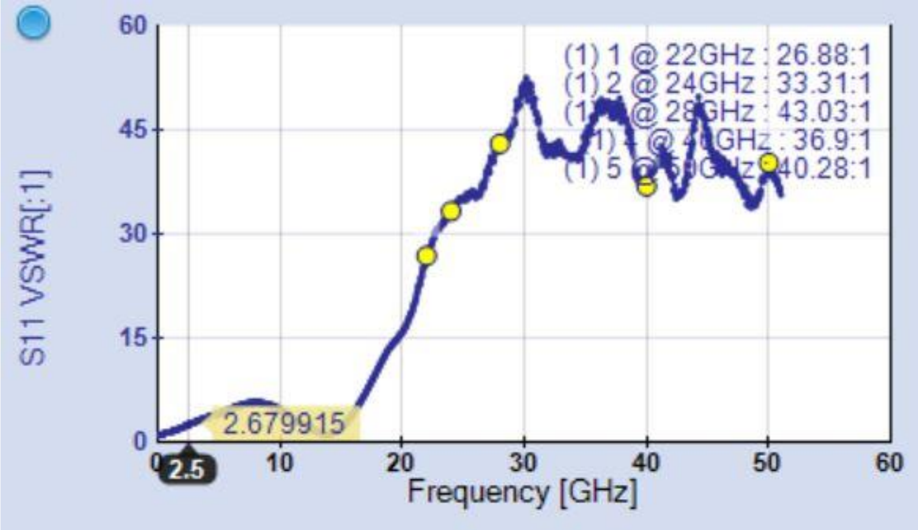
Electro-mechanical tuners is designed specifically for high frequency on wafer measurements.

The tuner’s low profile allows it to be placed within the wafer perimeter and allows for a direct connection between the probe tip and the tuner.

- Wideband coverage
- Possibility of hybrid Load Pull
- Fundamental and harmonic tuning
- Behavioral modeling

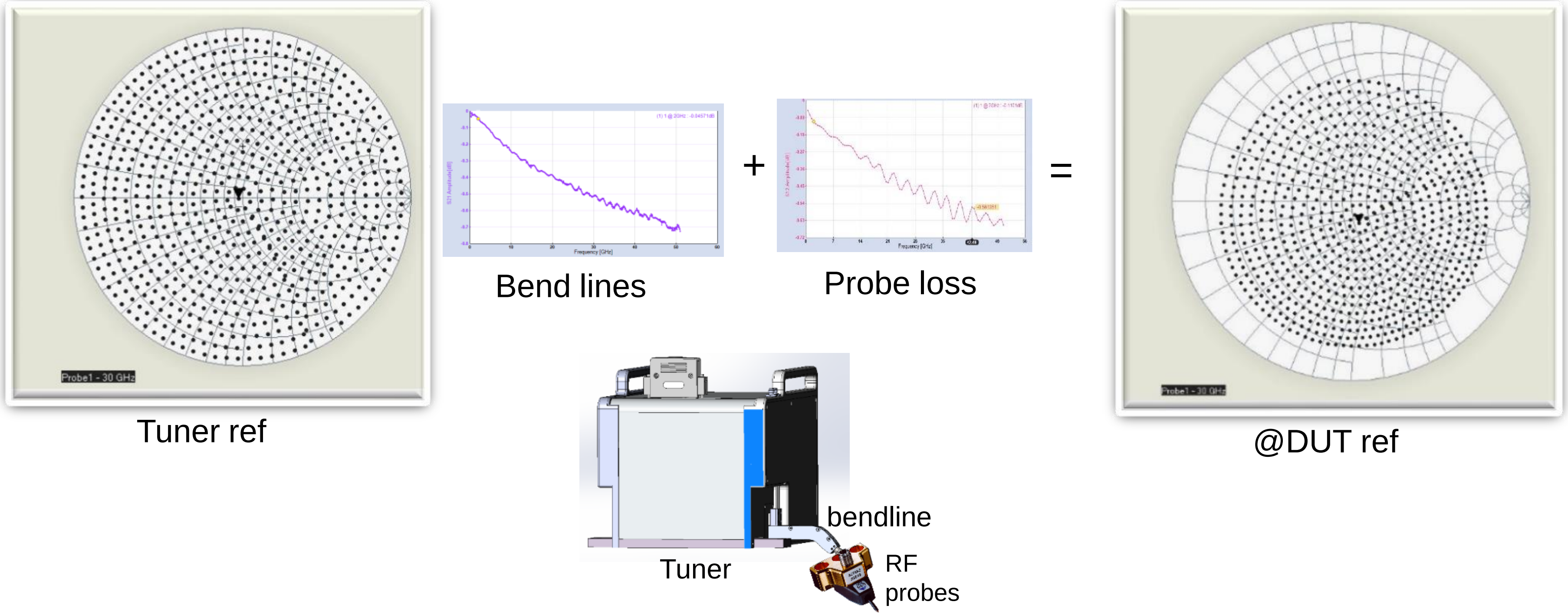
DELTA Tuners – Tuning Range

20GHz-50GHz High VSWR

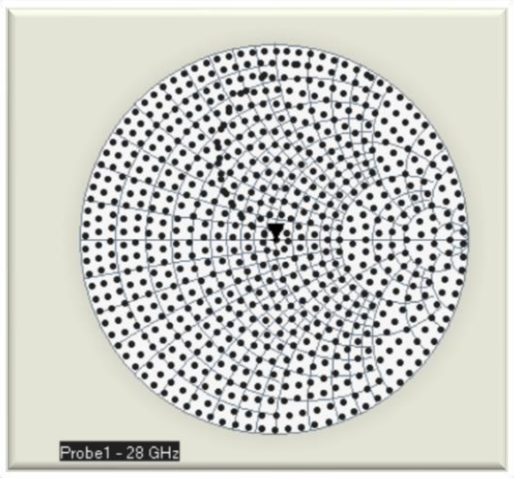


10GHz-67GHzGHz

Traditional Tuners – Tuning Range

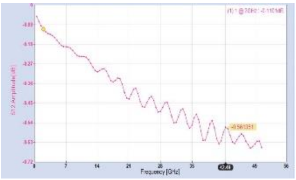


DELTA Tuners – Tuning Range



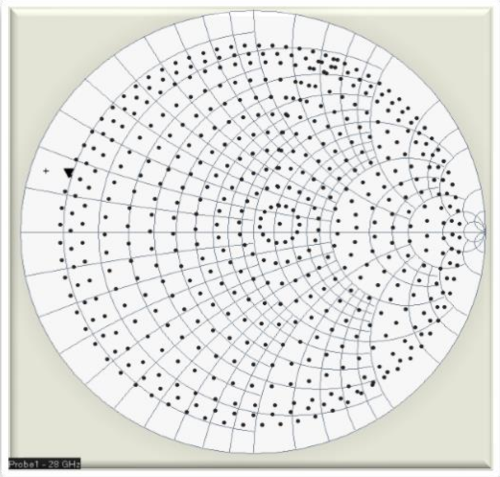
Tuner ref

+



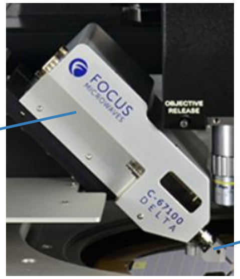
Probes loss

=



@DUT
Ref

Tuner

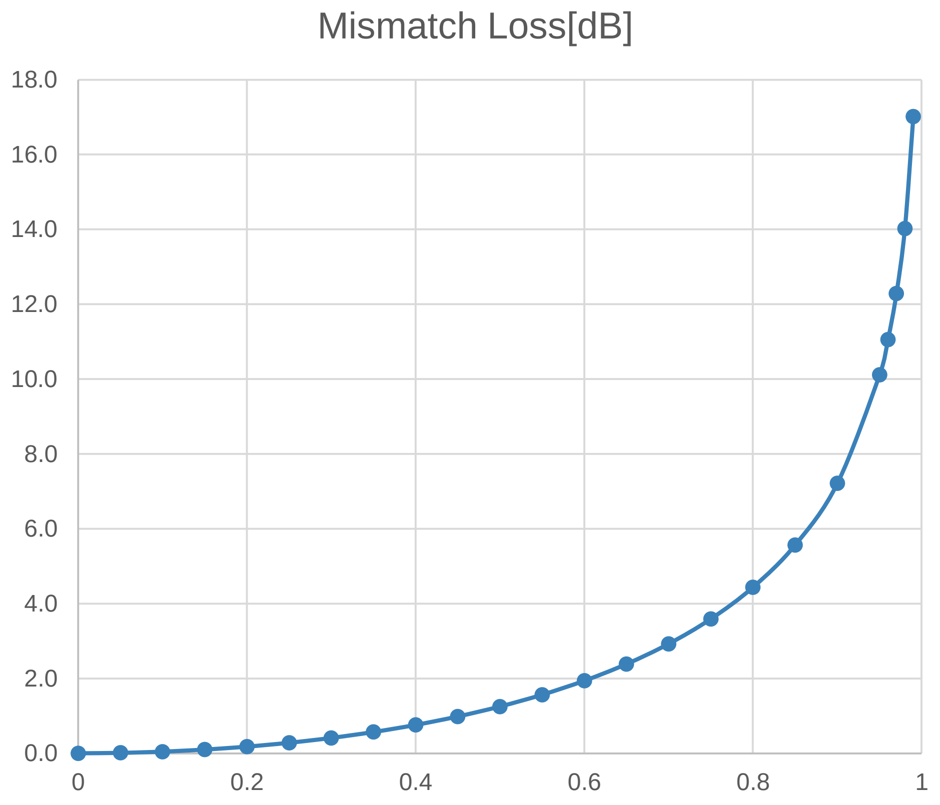


RF
Probes

Hybrid Active Loadpull

Table of Mismatch Loss & Impedance

Γ	ML[dB]	Impedance
0	0.0	50.0
0.1	0.0	40.9
0.2	0.2	33.3
0.3	0.4	26.9
0.4	0.8	21.4
0.5	1.2	16.7
0.6	1.9	12.5
0.7	2.9	8.8
0.8	4.4	5.6
0.9	7.2	2.6
0.96	11.1	1.0



Active/Hybrid Active Load Pull

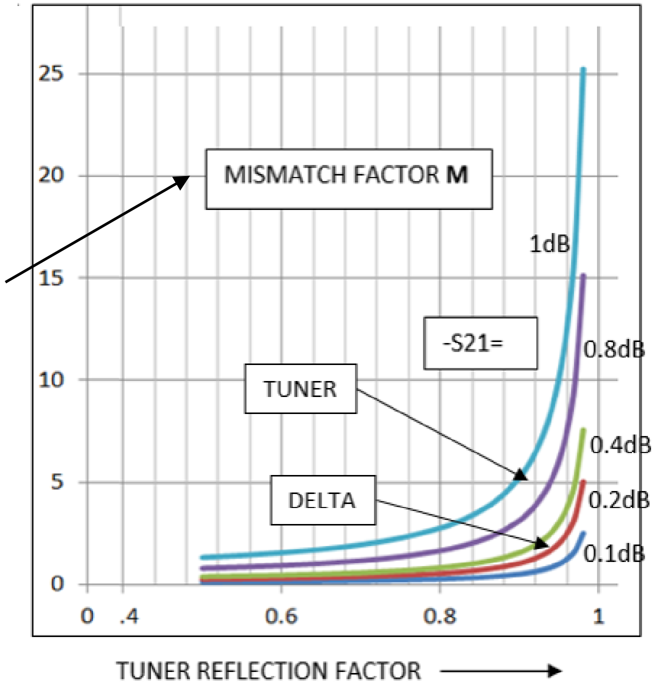
HYBRID LOAD PULL IS VERY SENSITIVE TO *INCREMENTAL* INSERTION LOSS

THE MISMATCH FACTOR ACCOUNTS FOR THE POWER LOST DUE TO MISMATCH AND INSERTION LOSS

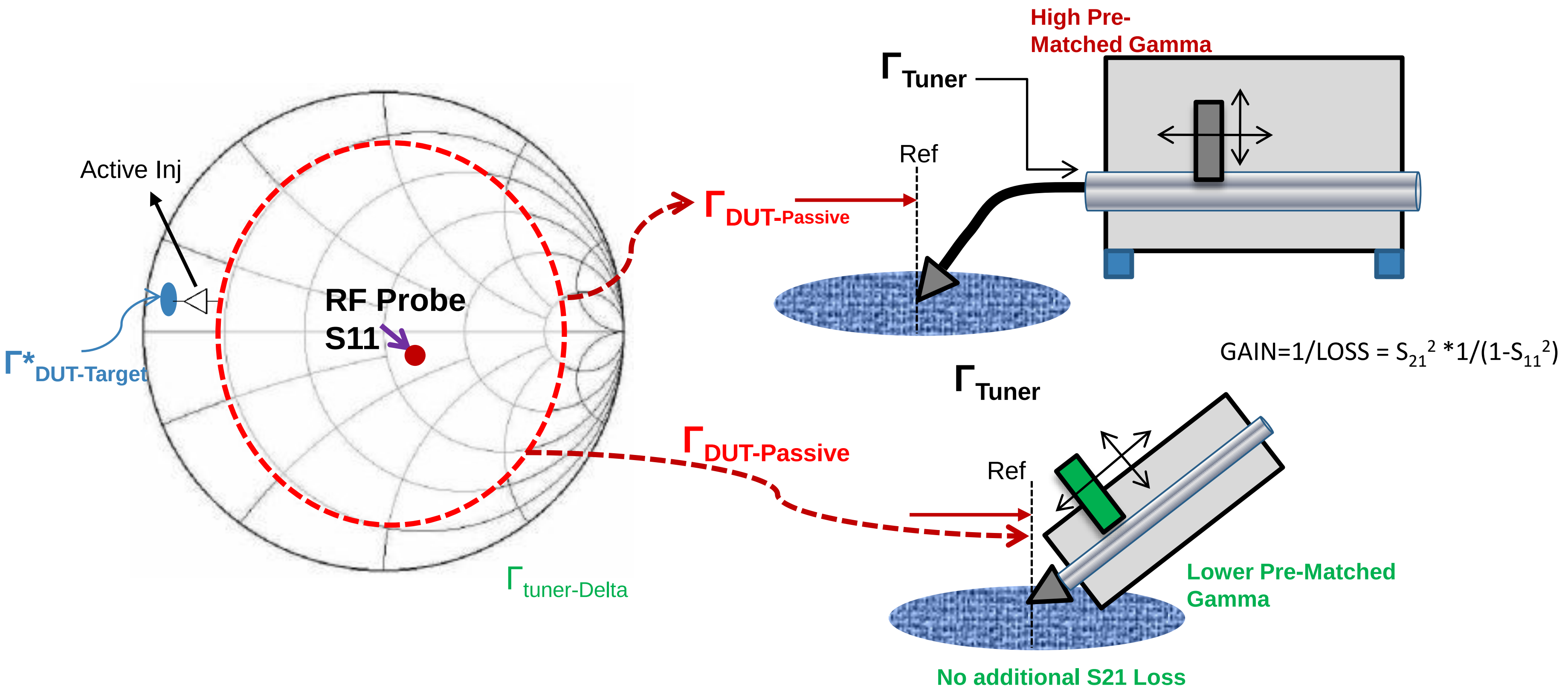
$$GAIN=1/LOSS = S_{21}^{2} \underbrace{\boxed{*1/(1-S_{11}^{2})}}_{M}$$

$$\mathbf{\Delta GAIN=2*\Delta S_{21}*M}$$

THIS SHOWS HOW MUCH INJECTION POWER IS NEEDED WHEN PRE-MATCHING WITH A REAL TUNER



Lower Feedback Power

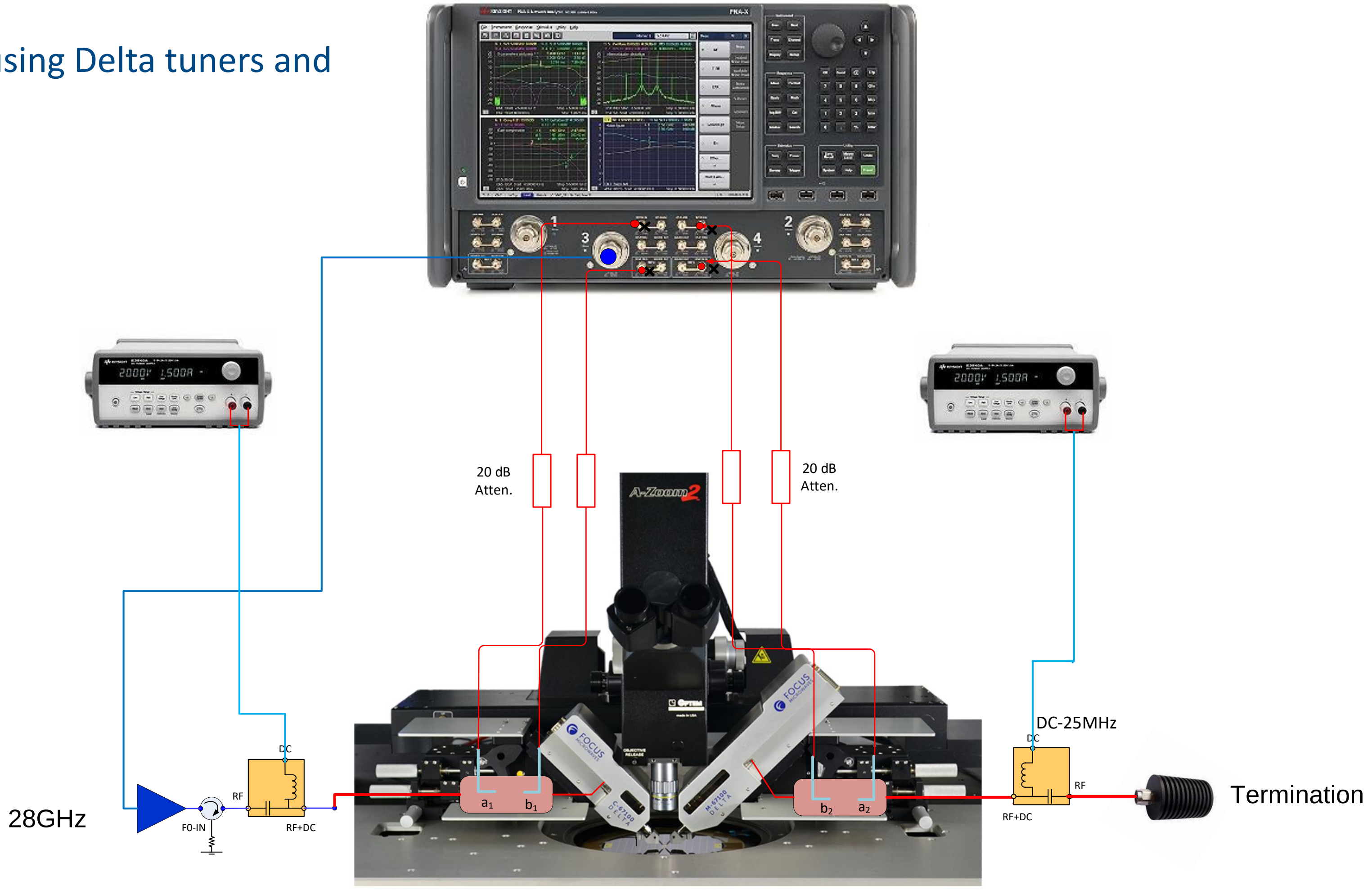


LP Measurement Setup

Fully integrated LP Setup using Delta tuners and PNA-X

F0 28GHZ

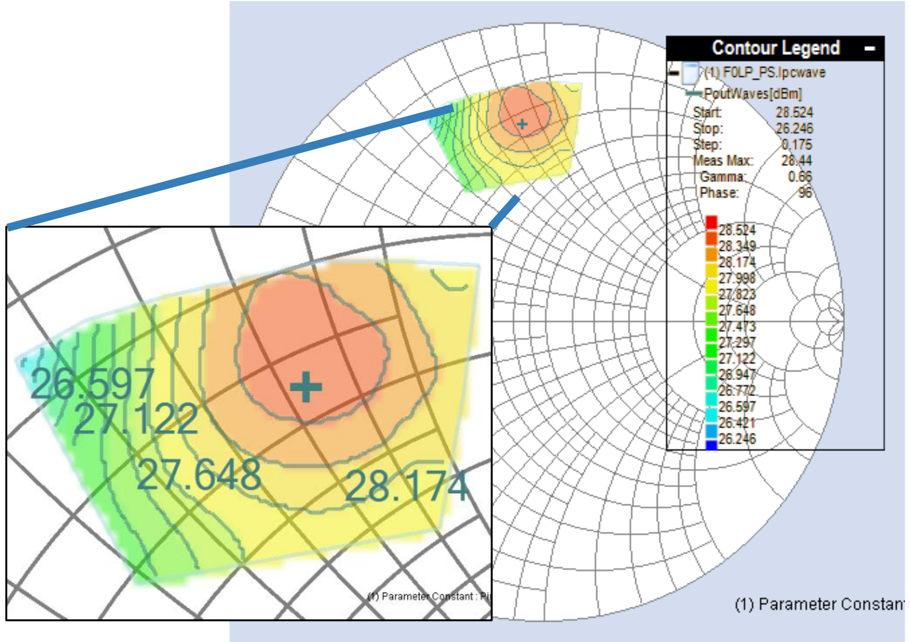
2F0 56GHz



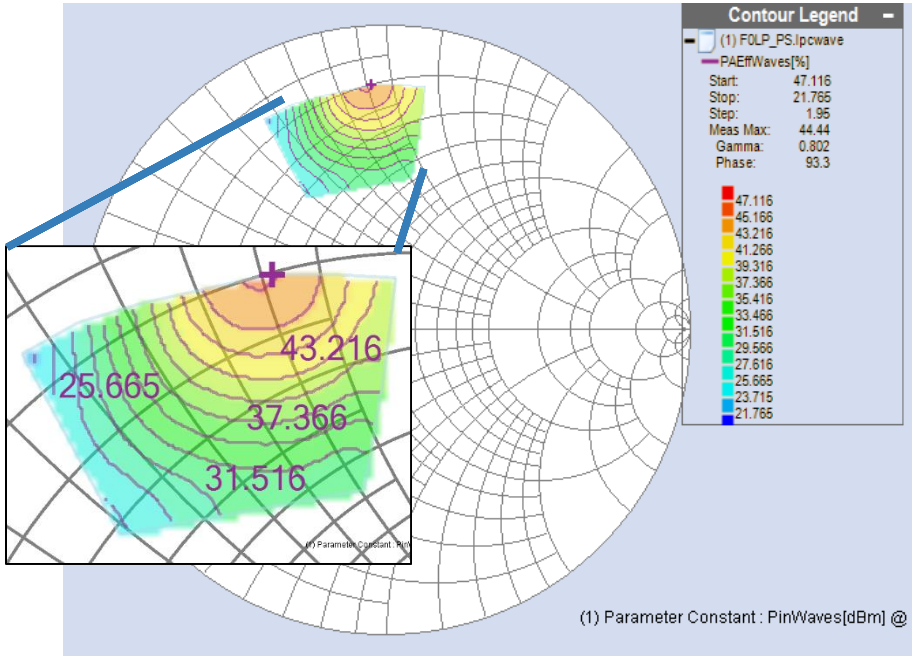
Device Load Pull Contours

Pout & PAE Passive Tuners

Pout@28GHz



PAE@28GHz

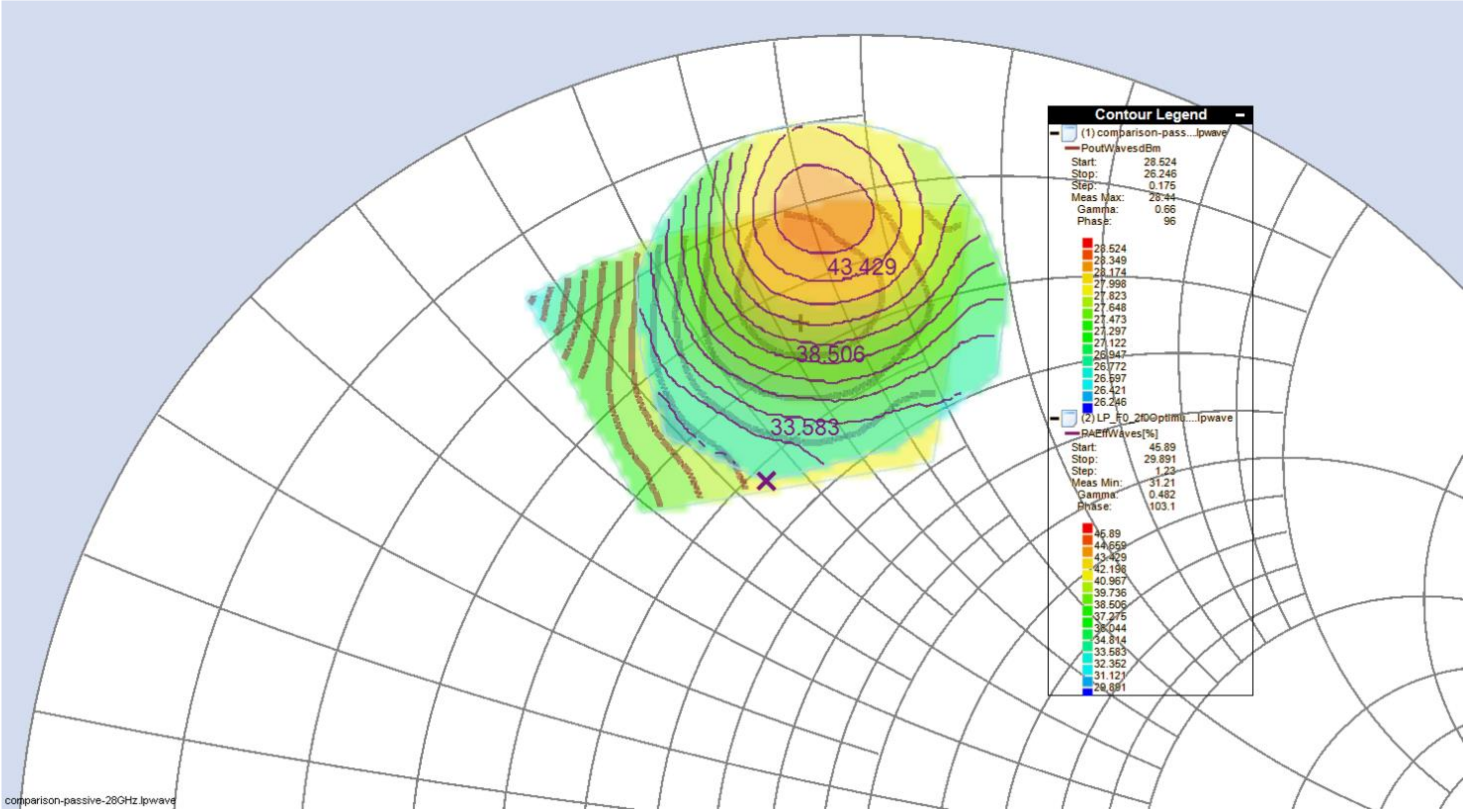


Device Load Pull Contours

Pout & PAE

Tuned for Max Power Point
Mag=0.694 Phase= 95.4 phase

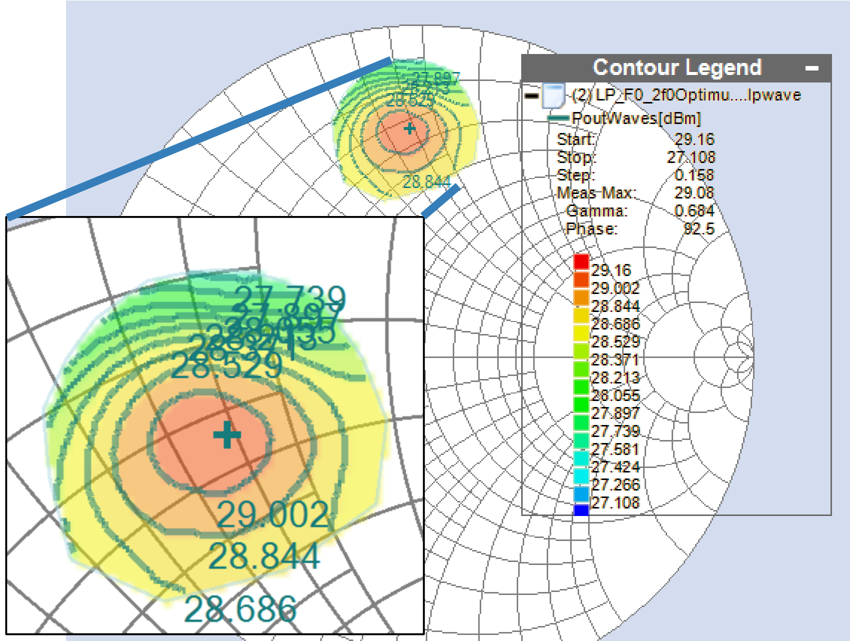
Tuned for Max PAE Point
Mag=0.787 Phase= 94.1 phase



Device Load Pull Contours

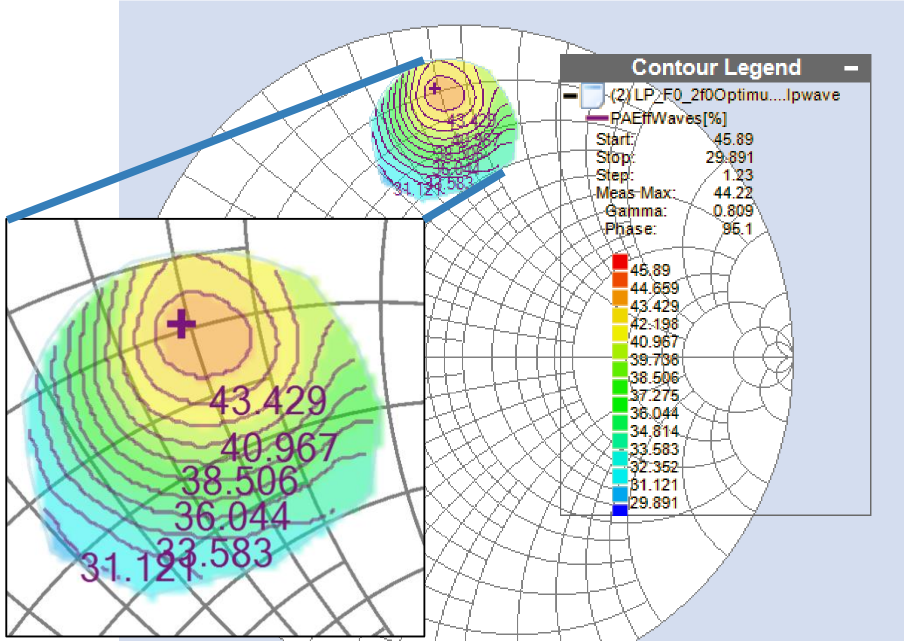
Pout & PAE Hybrid Active Mode

Pout@28GHz



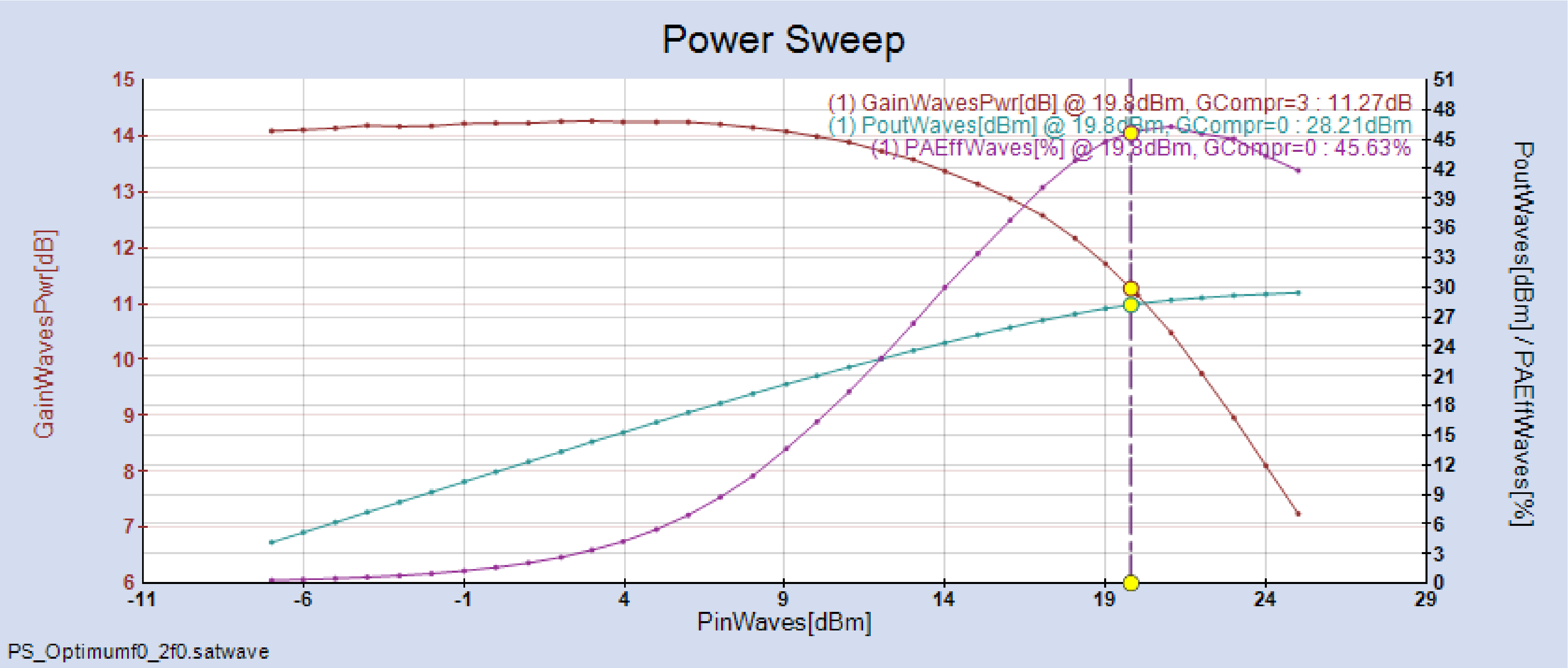
Tuned for Max Power Point
Mag=0.694 Phase= 95.4 phase

PAE@28GHz



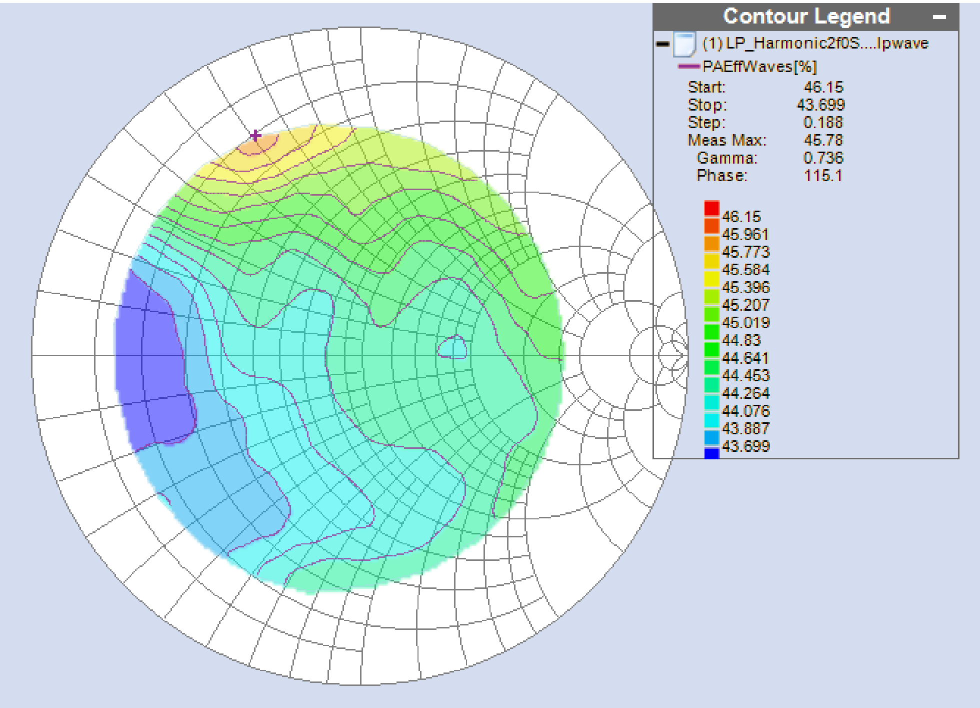
Tuned for Max PAE Point
Mag=0.787 Phase= 94.1 phase

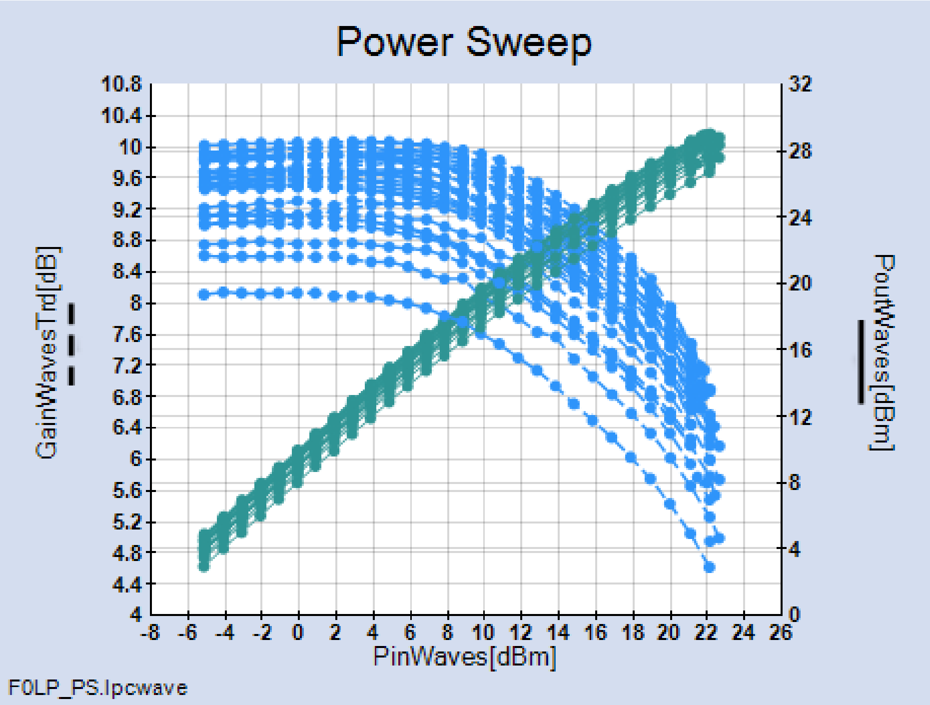
Device Load Pull Power sweep



Device Load Pull PAE Contours

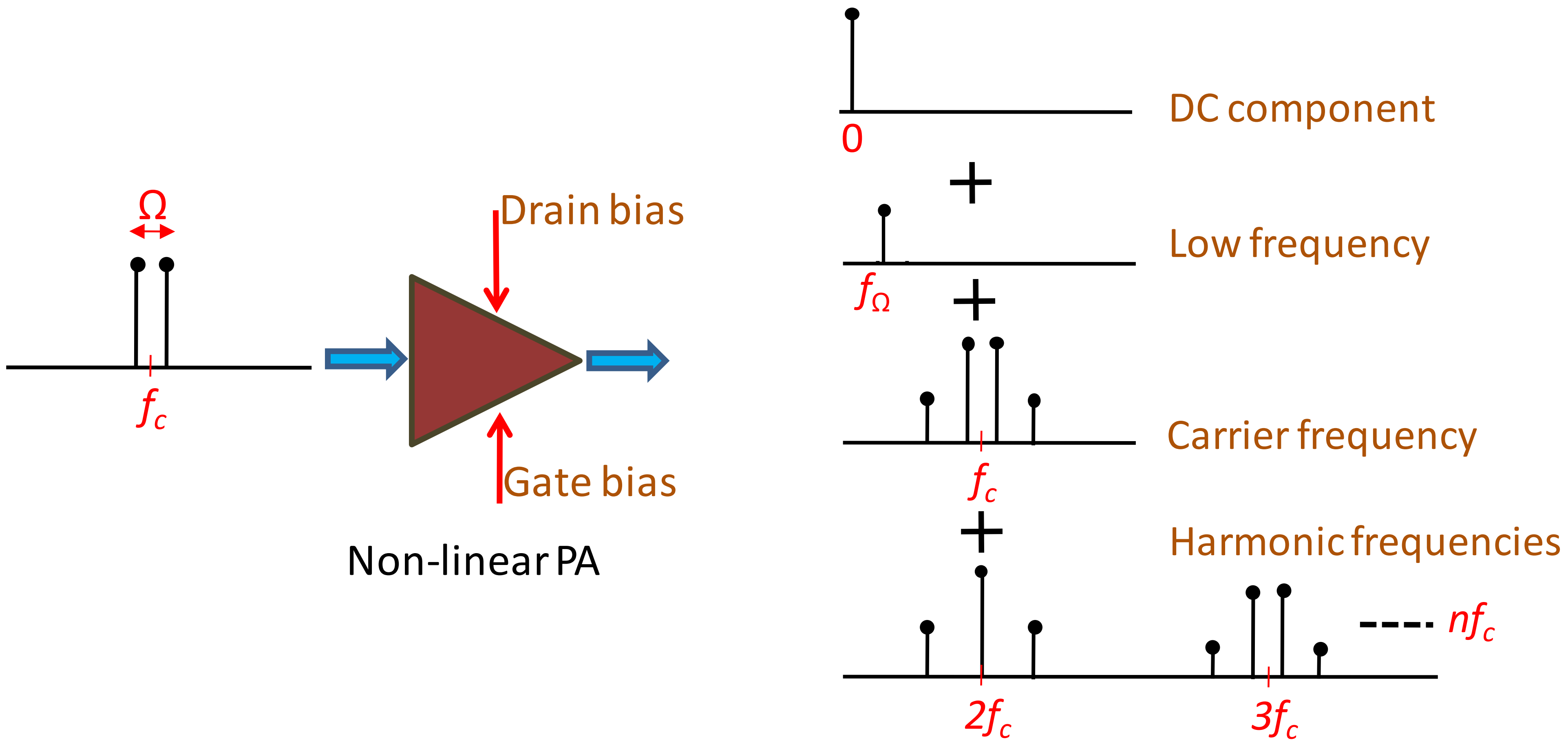
2*fo* Sweep





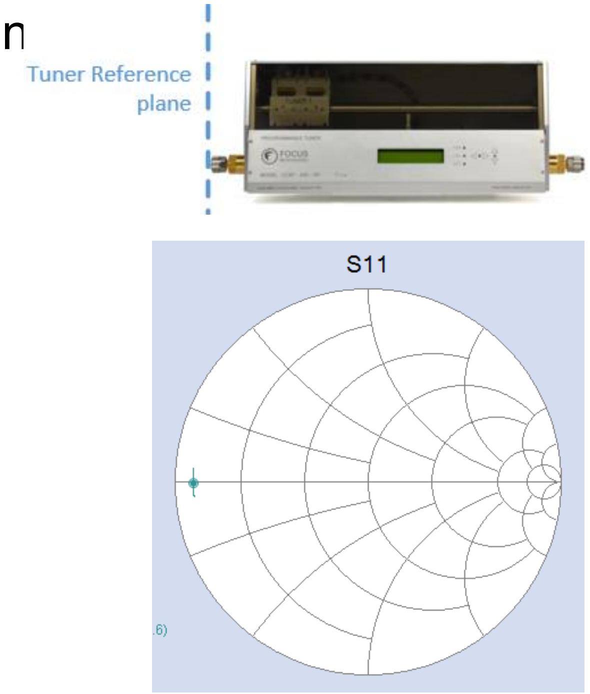
Baseband Impedance Control

Two Tone Spectrum

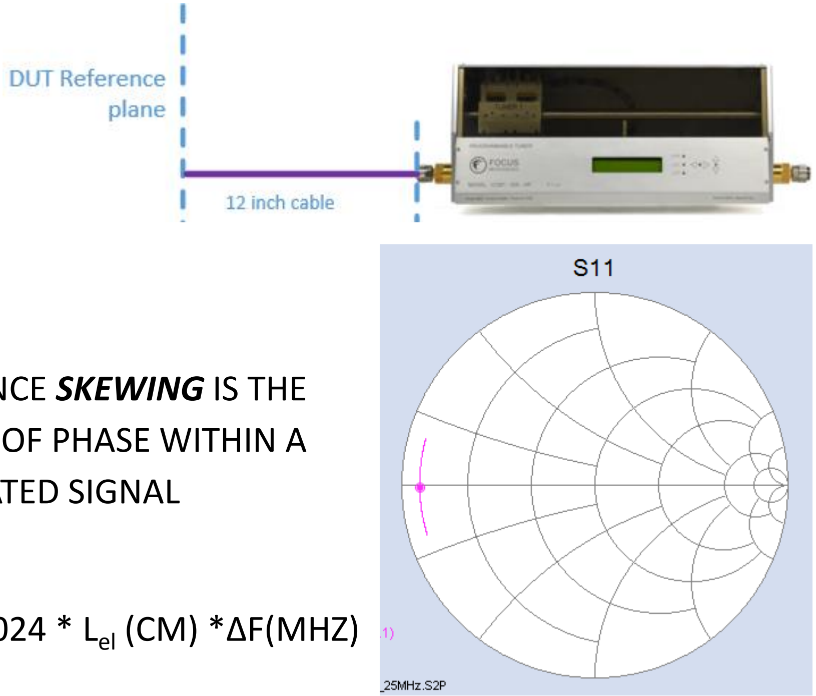


Reduced Impedance Skewing

25MHz (BW) @ tuner reference plan



- 25MHz (BW) 12 inch cable

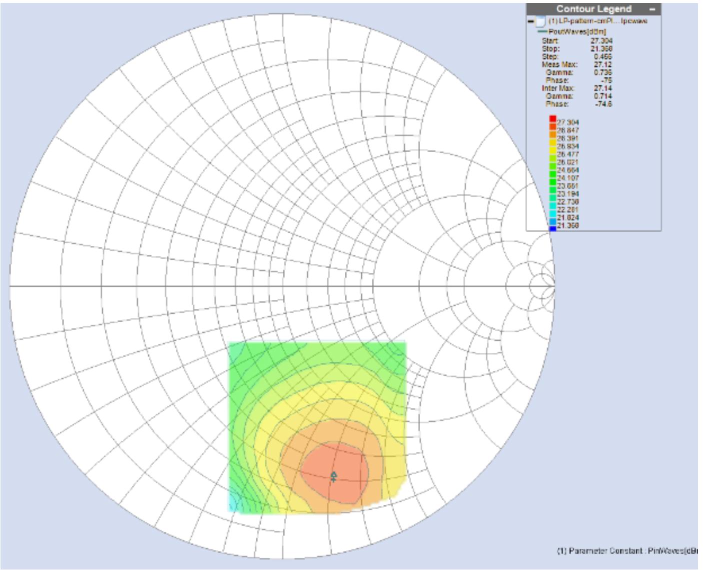


IMPEDANCE ***SKEWING*** IS THE CHANGE OF PHASE WITHIN A MODULATED SIGNAL

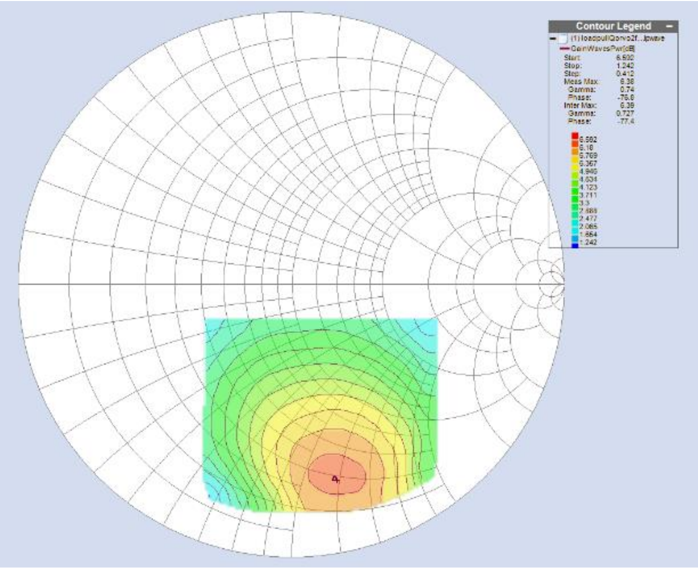
$\Delta\Phi° = 0.024 * L_{el}$ (CM) $*\Delta F$(MHZ)

Device Performance

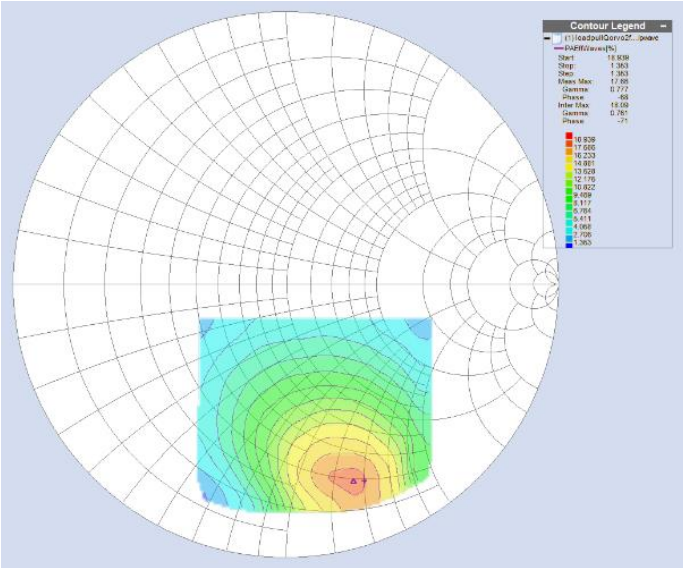
Fundamental Frequency: 28GHz



Output Power Contours



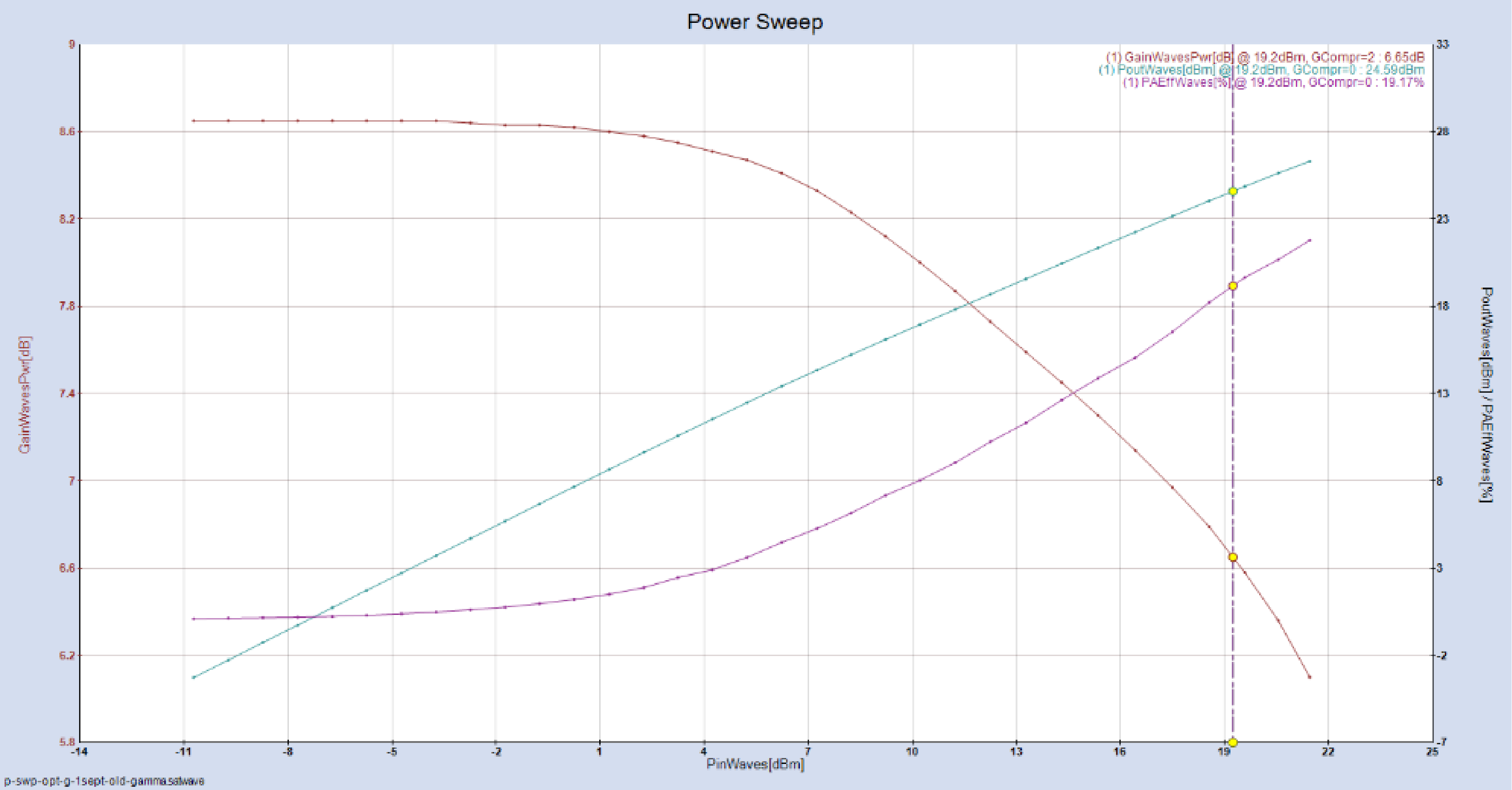
Power Gain Contours



Power Added Efficiency Contours

Device Performance

Power Sweep @ Optimum G_{load}



$P_{out\text{-}2dB}$ =24.59dBm
PAE = 19.54%

IMD Measurement under non-50 Ω

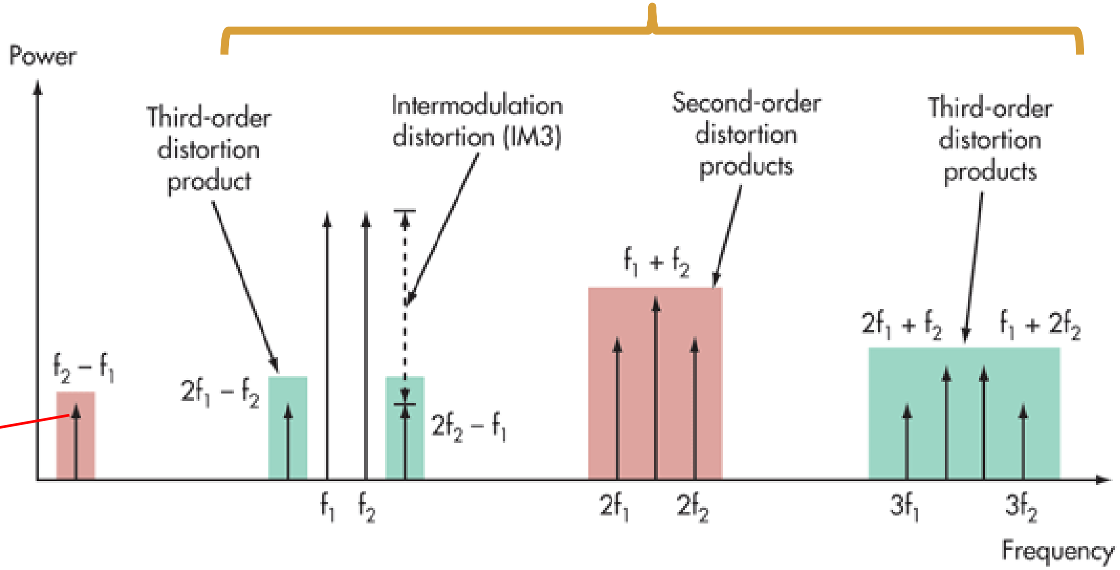
Meas 1- Impedance sweep at Centre frequency

a. 1MHz tone spacing
b. 10MHz tone spacing
c. 20MHz tone spacing

Meas 2- Impedance sweep at baseband frequency

a. 10MHz tone spacing
b. 20MHz tone spacing

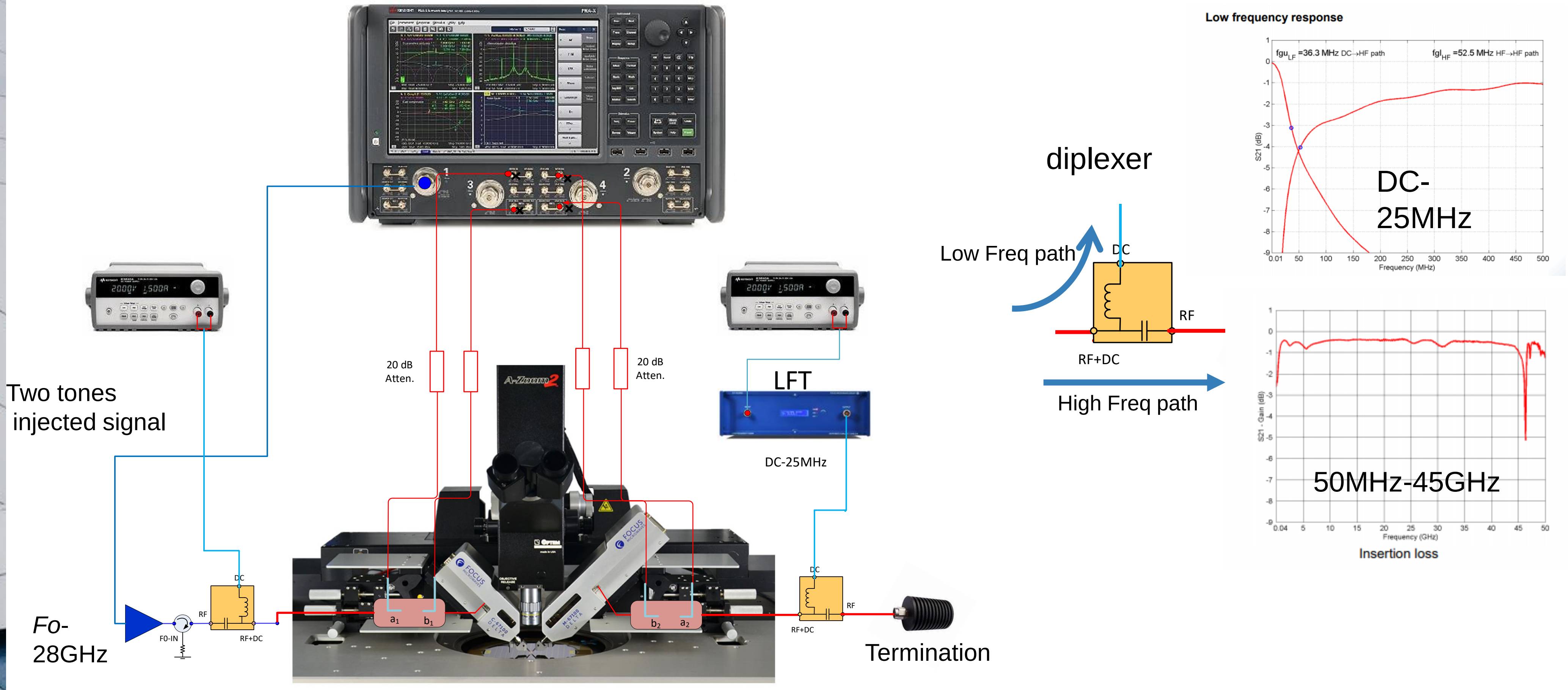
Non-50Ω load Impedence sweep controlled by Load tuner in RF path



Base band impedance sweep using LFT

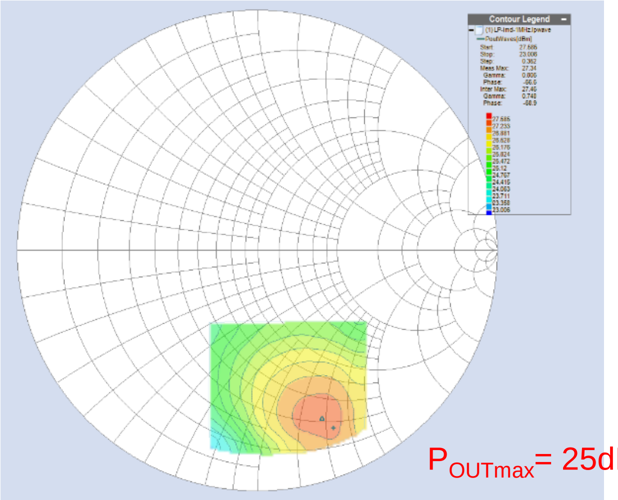
IMD Measurement Setup

Fully integrated IMD LP Setup using DELTA Tuners



IMD Measurements Case 1

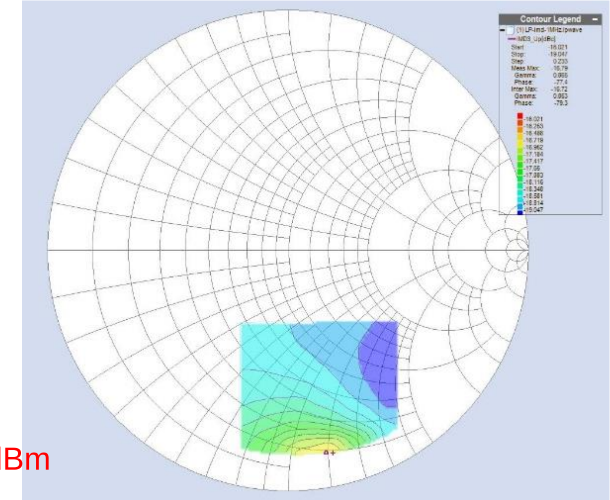
Fundamental Frequency: 28GHz
Tone Spacing: 1MHz



P_{OUTmax}= 25dBm

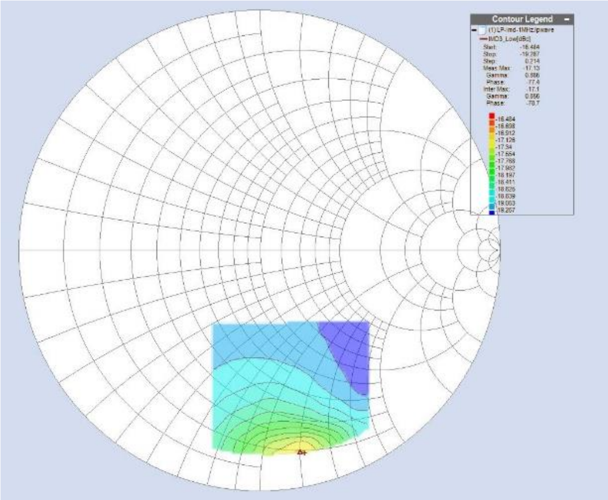
Output Power Contours

IMD_3 –swing
-19.9 to -16.4



IMD_3 -High

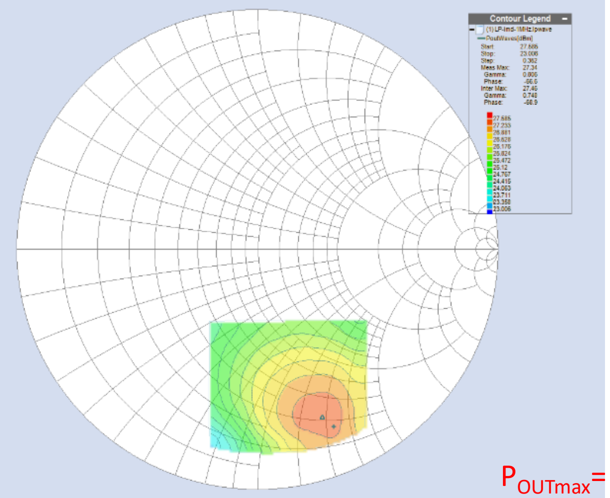
IMD_3 –swing
-19.0 to -16.0



IMD_3 -Low

IMD Measurements Case 2

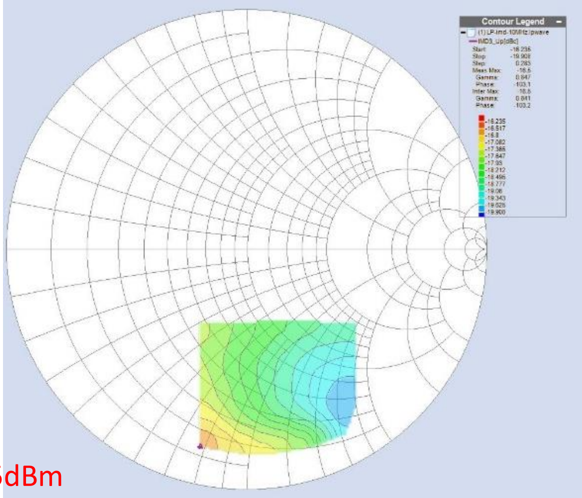
Fundamental Frequency: 28GHz
Tone Spacing: 10MHz



P_{OUTmax}= 25dBm

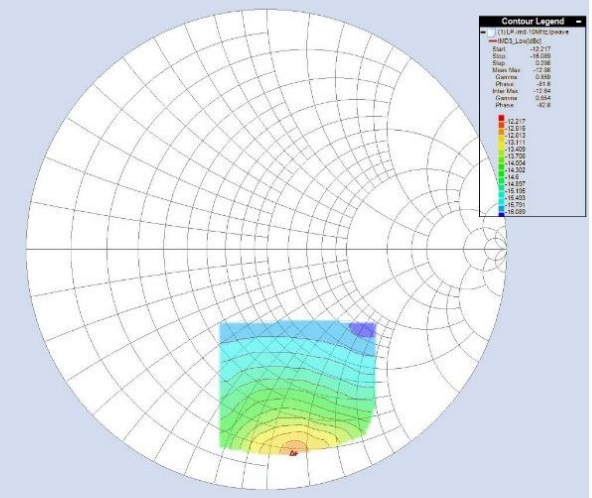
Output Power Contours

IMD_3 –swing
-19.9 to -16.2



IMD_3 -High

IMD_3 –swing
-16.089 to -12.27



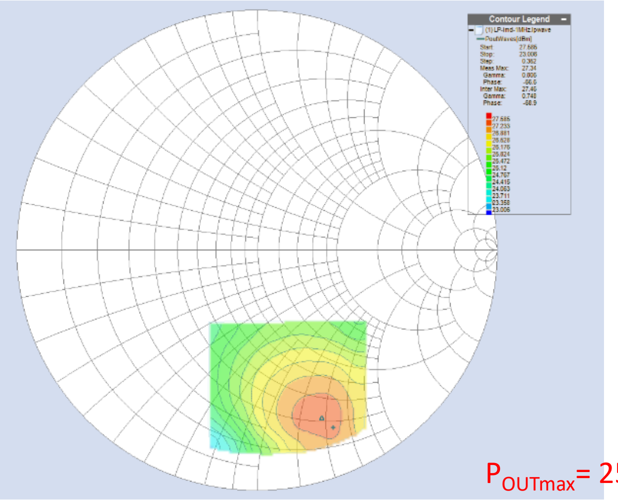
IMD_3 -Low

IMD Measurements Case 3

Fundamental Frequency: 28GHz
Tone Spacing: 20MHz

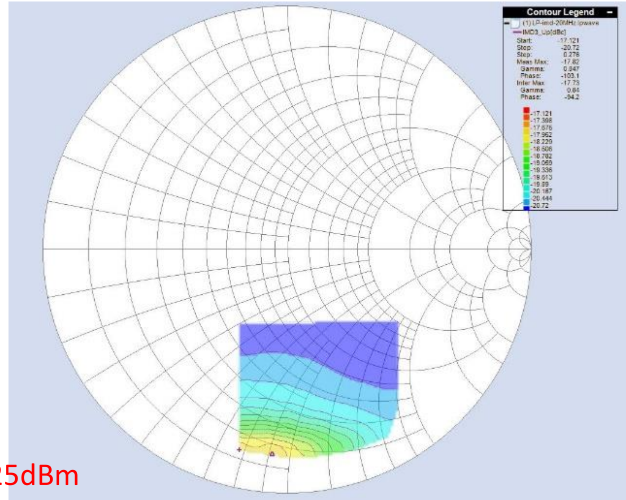
IMD_3 –swing
-20.7 to -17.12

IMD_3 –swing
-19.343 to -15.23

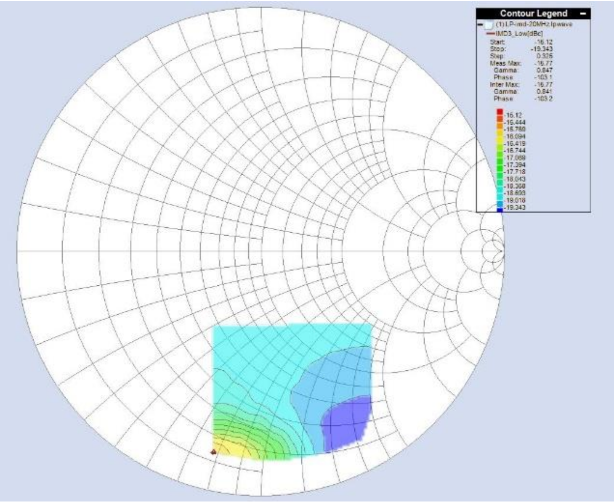


P_{OUTmax}= 25dBm

Output Power Contours



IMD_3 -High



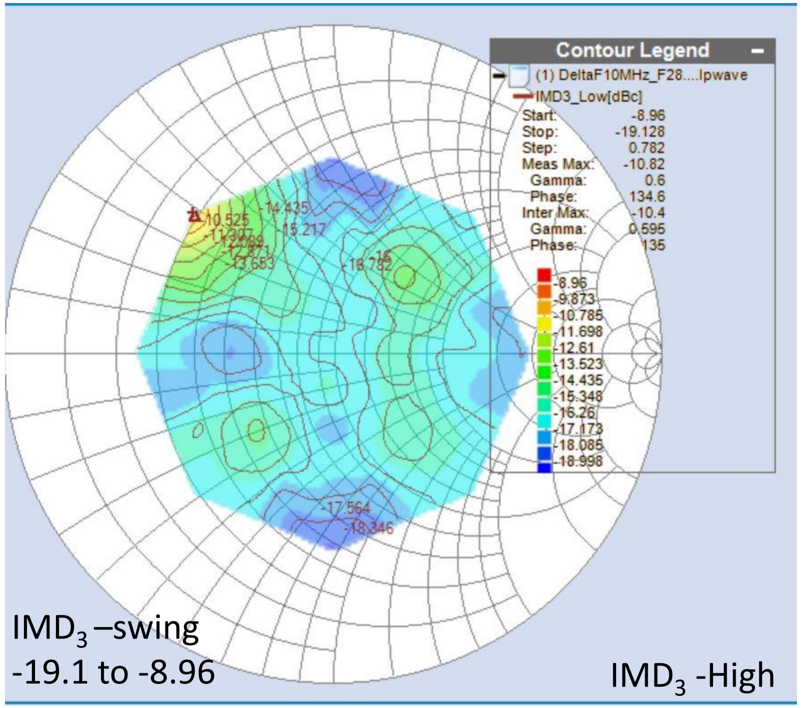
IMD_3 -Low

Different $\Gamma_{OPT\text{-}power}$ for both Pout and ACPR

Base Band Tuning Case 2

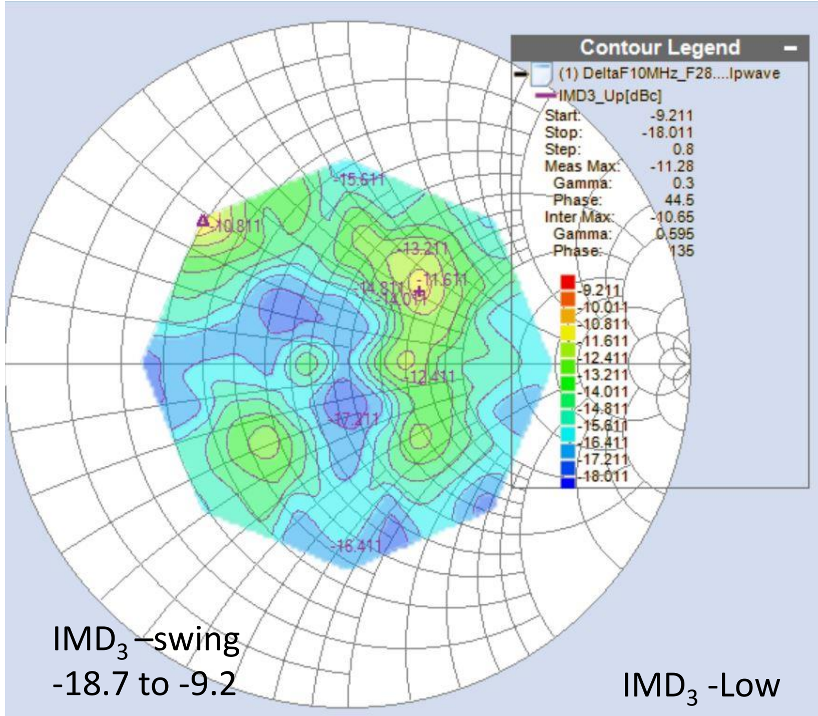
Fundamental Frequency: 28GHz
Tone Spacing: 10MHz

Fundamental load impedance fixed at optimum Pout
Load impedance varied at 10MHz using LFT



IMD$_3$ –swing
-19.1 to -8.96

IMD$_3$ -High



IMD$_3$ –swing
-18.7 to -9.2

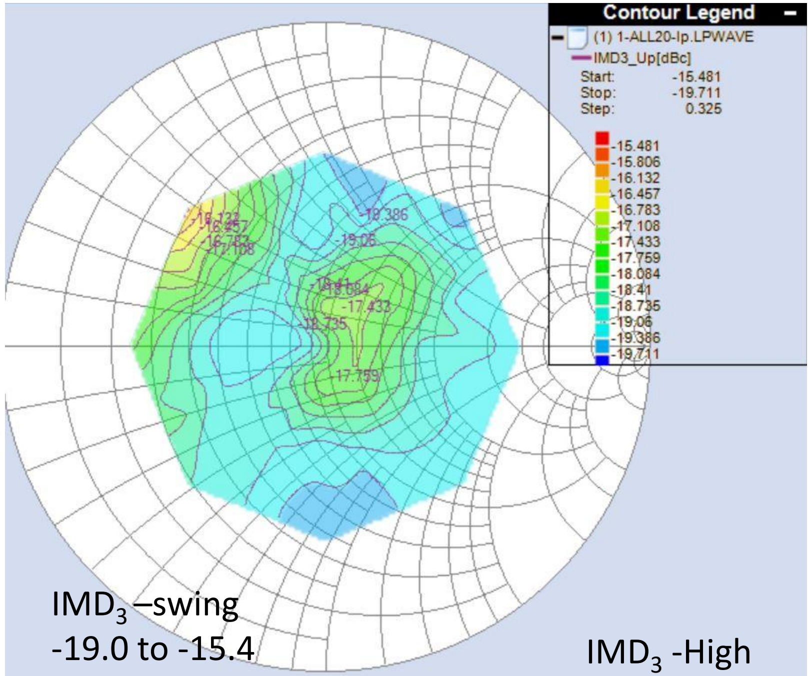
IMD$_3$ -Low

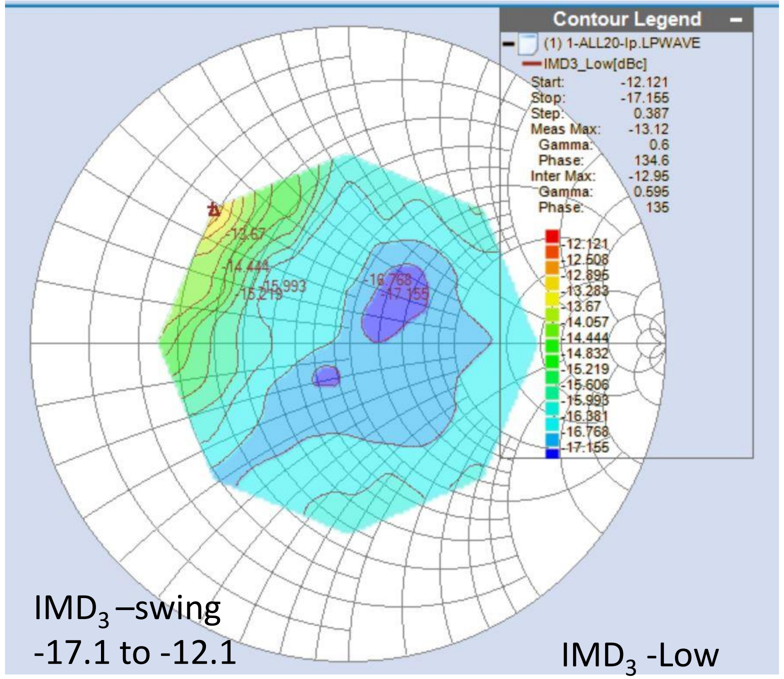
High Linearity achieved for both high and low side band at maximum $\Gamma_{OPT\text{-}Power}$

Base Band Tuning

Fundamental Frequency: 28GHz
Tone Spacing: 20MHz

Fundamental load impedance fixed at optimum Pout
Load impedance varied at 20MHz using LFT





High Linearity achieved for both high and low side band at maximum $\Gamma_{OPT\text{-}Power}$

Conclusions

For Advanced 5G applications Delta tuners offers multiple advantages over conventional tuners for enhanced LP measurements

- High tuning range
- Lower active power for hybrid active approach
- Less skewing
- Wider frequency bands
- More flexibility
    - Frequency range
    - Power capability